Automated Marking Device

Abstract

In swine production facilities, handlers traditionally rely on visual cues to identify animals requiring intervention, such as for market readiness or health issues. To enhance this process, a Swine Monitoring System has been developed, employing RFID tags to track pigs' time spent at drinking stalls and depth cameras to measure their weight. Despite this technological advancement, handlers still manually identify, and mark flagged abnormalities. Therefore, an automated marking device has been proposed to integrate with the existing Swine Monitoring System, streamlining the identification process. This device utilizes a spraying system installed within drinking stalls, with dual-nozzle modules emitting green for market readiness and pink for health concerns. The monitoring system generates a list of flagged pigs requiring marking, which is then communicated to the automated marking system. As pigs enter the drinking stalls, the system checks their RFID numbers against the list generated by the Swine Monitoring System to identify animals that need to be marked, and takes appropriate action based on the comparison. At day's end, a report of marked pigs is relayed back to the monitoring system, initiating a new cycle. This automated solution promises increased barn efficiency and enhanced swine well-being, ultimately bolstering pork production.

Acknowledgements

The team would like to extend our sincere gratitude to Dr. Raj Sharma and Vegard MacNeill Saetre, our esteemed clients, for their invaluable expertise and unwavering support throughout the duration of this project. Their insights and guidance have been instrumental in shaping the direction and success of our work. We are also deeply thankful to Dr. Tami Brown-Brandl, our acclaimed faculty advisor, for her mentorship, encouragement, and continuous support. Her expertise has been invaluable in navigating the complexities of our research. Additionally, we want to express our appreciation to UNL's Department of Biological Systems Engineering for their generous funding, which has enabled us to pursue this project and make significant strides in our research endeavors. Their support has been crucial in driving our project forward and achieving our goals.

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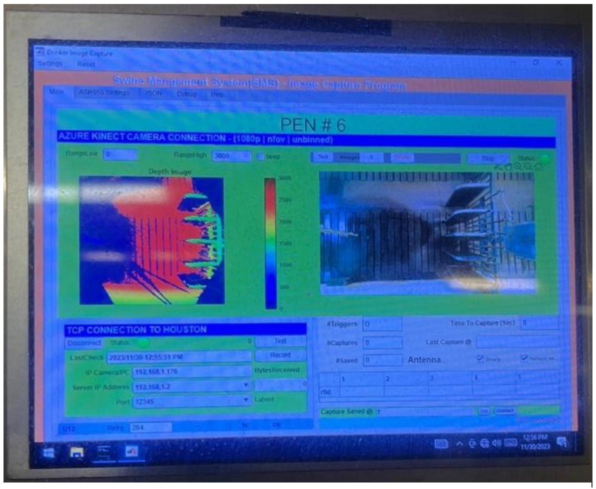
Background

In the current state of the pig industry, handlers are tasked with manually identifying animals that reach market weight or exhibit signs of illness or injury. This identification process heavily relies on the handler's experience and observation skills. Complicating matters, each pen can house anywhere from 20 to 200 pigs, making accurate recognition challenging within the confines of a small, enclosed space. Given the large population of pigs housed within these barns, there exists significant potential for producers to avoid substantial fees if pigs fail to meet market weight requirements. Any deviations from the optimal market weight, which is between 260 and 280 pounds, can result in additional profit losses for the producer during processing. Moreover, many producers operate large-scale farms. The laborious task of monitoring and inspecting pigs becomes a timely responsibility, and even the biggest operations are in a crunch for time to complete check-ins before the day is over.

Figure 1. *Swine Monitoring System Barn Configuration.* Swine Monitoring System set up in the pig barn on the drinking stalls. Electrical box to the left on the wall shows a digital monitor of the weight system.

Our client has successfully deployed a Swine Monitoring System (SMS) across multiple swine finishing facilities. This innovative system utilizes depth images to accurately estimate the weight of pigs as they visit drinking stalls. As depicted in Figure 1, the monitoring system is intricately integrated into the infrastructure of the drinking stalls, incorporating essential electrical components. The camera applies sophisticated algorithms to calculate the distance to each pixel, as outlined by Brown-Brandl et al. (a). This distance data is then processed by a computer, utilizing a specific formula to estimate the volume of the detected pigs, as illustrated in Figure 2. The system is capable of real-time weight analyzation, interpreted in Figure 3. Remarkably, current estimations of pig weight achieved at the drinkers boast an impressive accuracy rate of approximately 99% (Condotta et al., 2018a).



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IP Camera/PC 192.168.1.176

Server IP Address 192.168.1.2

Port 12345

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Time To Capture (Sec) 0

Retry 264

Figure 2. *Stall Monitor Screen.* Digital screen showing real-time monitor status and data collected.

Another integral component of the Swine Monitoring System is the Radio Frequency Identification (RFID) readers installed at the drinking stalls. These readers continuously scan the RFID tags attached to the pigs every 10 seconds while they are drinking, effectively identifying the specific stall each pig occupies. As depicted in Figure 3, the association of each pig's weight with its unique RFID number, showcasing an essential component to the Swine Monitoring System. Subsequently, the microcomputer records the duration of each pig's feeding session, as outlined by Brown-Brandl et al. (2018). This data proves invaluable as it allows for the plotting of individual pigs' feeding times against their overall consumption patterns, shown in Figure 4. By doing so, the system can detect deviations in consumption trends, serving as an early warning mechanism for potential illness or injury among the swine. This proactive approach enables timely intervention before such issues are identifiable to even the most experienced handlers, ultimately enhancing the welfare and health management of the pigs.

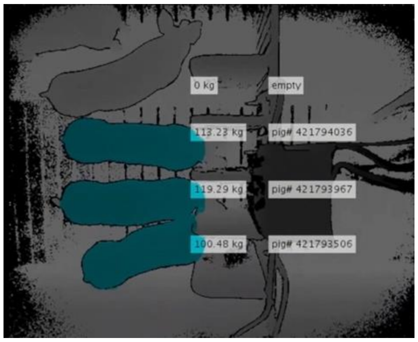


Figure 3. *Real-Time Weight Estimation.* Real-time weight analyzation of pigs detected in each stall.

Presently, despite the implementation of the swine monitoring system, the process of flagging a pig for intervention still necessitates the costly and inefficient involvement of a handler. In our client's research barns, once a pig is identified for management intervention, a handler must navigate through the pen equipped with an RFID reader to locate the correct pig. This task presents considerable challenges, as the RFID tags attached to the pigs' ears are approximately the size of a quarter. Upon locating the RFID tag, the handler then faces the daunting task of extracting the individual pig from the pen. Subsequently, once the pig has been successfully retrieved, it undergoes handling by multiple individuals, ranging from caretakers to livestock transporters. These challenges represent just a subset of the obstacles handlers encounter when managing pigs requiring intervention.

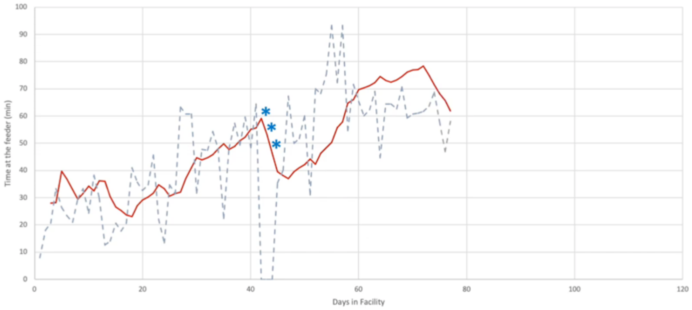


Figure 4. *Time at Feeder Versus Days in Facility Graph.* Graph of days in facility versus time spend at the feeder. The blue asterisks indicate abnormalities, resulting in a flagged RFID tag needing intervention.

Implementing an automated system for visually identifying pigs in need of management intervention holds the promise of significantly enhancing the quality of life for the pigs. With such a system in place, pig caretakers can promptly administer medication and implement injury recovery plans, thus improving overall animal welfare. Moreover, for producers, the adoption of an automated identification system translates into substantial cost savings and heightened labor efficiency. Presently, experienced farmhands are challenging for producers to recruit and retain. With automation, the need for highly skilled labor diminishes as the system lessens the requirement for manual identification of pigs requiring intervention. Consequently, a reduction in the labor force results in payroll savings for the producer. Furthermore, the precision and accuracy afforded by automation yield additional savings for producers during processing, as pigs are identified with greater efficiency.

Stakeholder Analysis

Animal caretakers are affected because their job becomes simpler and more efficient since they will identify what pigs were marked and move them to their associated areas to get treated or prepared for market.

Pig producers in general are impacted by the automated marking device because this is a tool that can be implemented into their operations to increase productivity and potentially reduce expenses, which both can increase profit.

Pork consumers could be influenced by this device because of perceived improvement in animal well-being, and potentially the lower of meat prices may decrease due to a potential decrease in production costs.

The **clients** are stakeholders because they are entrusting the design team to create this product to be functional for their research.

The **design team** are also stakeholders to their own project because they are ensuring this project is successfully completed to meet the university's graduate requirements.

The University of Nebraska-Lincoln Biological Systems Engineering Department is involved in this project because they are providing resources to help the design team create a functional product.

Ear tag and RFID equipment manufacturers are stakeholders because their technology plays a major role in the performance of both the swine monitoring system and the automated marking system. Furthermore, hog feeder manufacturers are also affected because their products are utilized to gather information by the swine monitoring system which then triggers the marking device to spray while the animal is still at the feeder or drinker.

Veterinarians and animal pharmaceutical companies, such as Merck Animal Health, can be impacted by this device because they invest in technology that can improve the use and effectivity of medicines and antibiotics.

Animals are an important stakeholder for this design because it could improve their well-being. Once the pig is marked for being sick, it can be treated in a timely manner and return to the pen amongst the other, healthy pigs.

Problem Statement

A need exists to design and build an automated marking device integrated with the current Swine Monitoring System to help producers quickly identify pigs in need of management intervention.

Goal

Automate the process of visually marking pigs and produce a functional device to aid producers in identifying animals in need of management intervention.

Objectives

- Determine the spray characteristics needed to effectively mark the pigs ranging in weights from 30 to 300 pounds.
- Design a communication protocol compatible with the Swine Monitoring System to trigger the automated marking mechanism.
- Evaluate the functionality and effectiveness of the prototype.

Criteria

- Mountable to a currently existing structure.
- Add a visual dot to the neck or upper shoulders of the pig.
- Spray two different colors for market-ready weight and unhealthiness
- Paint is durable enough to stay on for at least 2 days.
- Paint should not contaminate any other surface than the pig.
- Automated marking system should communicate with the Swine Monitoring System by sending information back when pigs are or are not sprayed.

Criteria represent desirable features that enhance the design's effectiveness, although not essential for project completion. Firstly, the spray bar should be designed for easy mounting onto existing structures like fence railings, facilitating mobility and applicability across various barns and pens. Optimal pig marking involves placement between the shoulder blades or on the neck, ensuring consistency regardless of pig size. It's recommended to use two distinct colors for pig marking: one for indicating market weight and another for highlighting health concerns. This dual-color system streamlines efficiency by clarifying reasons for pig removal from the pen. Additionally, paint should remain visible on the pig for at least two days, accommodating handlers who may not check pens multiple times daily. To prevent confusion, the spray system must exclusively target pigs, avoiding painting other surfaces like floors, stall doors, or neighboring pigs. Lastly, the automated marking system should sync with the Swine Monitoring System, providing feedback on sprayed or unsprayed pigs to prevent unnecessary re-spraying or ensure continued flagging of unmarked pigs.

Constraints

- Entire system cannot permanently obstruct swine monitoring camera view.
- System must withstand the cleaning procedure in the barn that includes pressure washers and disinfectant solutions.
- Electronics on the system must be waterproof.
- Product cannot be a safety hazard to pigs.
- Spray product must be animal safe.
- Output pressure of the paint being sprayed must be below 100 psi.
- Spray bar and nozzles must fit dimensions of drinking stations – 320 mm between stalls, 1 m tall stall doors, and 500 mm deep into stalls.
- Electronic system needs to integrate input from current swine monitoring system.
- Marking system cannot exceed 80 dB of sound.
- Cost of four spray-bar systems must not exceed $1,500.
- Marking system must accommodate the sizes of the pigs between 8 and 30 weeks old.
- Marking system must be automated.

Constraints delineate essential requirements for completing the project safely and effectively. Foremost, the spray bar design must not obstruct the camera view, crucial for accurate weight detection of pigs. Waterproofing is imperative as the barn and stalls undergo high-pressure washing and disinfection after pig cycles, necessitating all components, including electronics, to withstand water exposure. Safety is paramount; hence, no part of the contraption should pose a hazard to the pigs. Additionally, to prevent interference, the product should be inaccessible to curious pigs. Pressure of paint spray should not exceed 100 psi, considering similarities between human and pig skin penetration thresholds (Uhm et al., 2023). Dimensions of the spray bar must fit within stall specifications, ensuring alignment of nozzles with stall centers for precise marking. Noise levels during marking must not exceed 80 dB to avoid startling pigs away from drinkers, as loud sounds can trigger defense mechanisms (Talling et al., 1996). Integration with the Swine Monitoring System is crucial for tracking pig data. Cost-effectiveness is vital, with the total expense for four systems not surpassing $1,500, aligning with handler wages. Lastly, the spraying system must accommodate pigs of varying sizes, delivering accurate marking regardless of age, from arrival at 8 weeks to maturity at 30 weeks.

Global, Social, Cultural, Economic, and Environmental Considerations

Global

Swine operations across the country and world may not have the capabilities to implement such a technology directly into their barns or operations. For example, in Mexico and Vietnam, pig producers graze their swine in open, outdoor layouts, so installing electronics into outdoor feeders could be more difficult. Therefore, this product will be easiest to apply in modernized swine facilities, which could affect the use of the automated marking system. Furthermore, swine barn facilities have different features in other countries. Some European countries allow natural light to infiltrate the barn or have open layouts. For this product to be utilized worldwide, the design cannot be affected by weather, UV rays, or other natural elements, and it must be adaptable to facility needs.

There are international guidelines in place for pig production, including how facilities are constructed and the components within the operation that encounter the pigs. The NSF Global Animal Wellness Standard is one document that outlines specific measures needed to take to ensure the pigs are well taken care of (NSF International, 2019). For instance, the feed and water facilities must be appropriate for size and age, so that is one consideration needing to be accounted for with this product. Additionally, any equipment in the pen must be free from sharp edges or protrusions and is always operating correctly to prevent injury or illness.

Social

Recently, there has been a significant increase in concern for animal farm production conditions from animal rights activists. They could potentially be disturbed with the method of pig marking. However, this system may enhance animal well-being as the pigs receive care sooner than with manual inspection, which can lead to a more positive reaction from the public. Animal pharmaceutical companies like Merck, Zoetis, and Boehringer Ingelheim are invested heavily into Precision Animal Management technologies, which allows them to stay at the forefront of innovation, improve animal health outcomes, and capitalize on emerging market opportunities.

Another consideration is the technical expertise of the swine barn owners and operators. The employees interacting with the system must have knowledge of the technology implemented to troubleshoot and work the device.

This automated marking device can impact operational hiring decisions. There could be a shift in the type of employee hired due to different demands and knowledge required to operate this system. Furthermore, it is difficult to hire people to a farm, so it is also difficult to develop the knowledge and experience in new employees to correctly identify swine in need of management intervention.

Another aspect worth considering is the turnaround time to identifying a sick pig and treating it. With the current manual marking process, pigs could be sick for multiple days before being treated. Often the handlers or managers will decide to administer antibiotics, or other medicines, to all the pigs whenever this occurs. This leads to a rise in concern from pharmaceutical companies about antibiotic resistance in pigs and other animals.

Cultural

Three religions, Islamic, Judaism and Seventh-day Adventists, have both outlawed the consumption of pork. This means that there is no potential for our design to be adopted for swine facilities in these cultures.

There are also cultures that limit the use of modern technologies, so our product would not be appropriate for their operations. The Amish are one culture group that are reserved in their way of life in that they do not use or implement modern technology and electricity and some Islamic cultures forbid marking animals, so these cultures may be hesitant to adopt this technology.

Economic

An economic advantage of our automated marking device is that it enhances the time efficiency of a pig handler. This could help the owners hire employees with less training and experience, which broadens the range of applicants and could help bring more help into the operation. However, if labor is cheap – such as in some foreign countries – and the operations have no issue with labor shortage, then the system would cost more than it would to pay people to handle and mark the pigs, so it would not be applicable to those operations.

This system also has a high initial investment cost, which could be problematic for some operations. Our device will integrate with the current camera monitoring system, which by itself is expensive. Therefore, small operations or poorer economies around the world may not be able to purchase the whole system at once. Financial plans may need to be put in place to limit the challenges with the cost of the automated marking system.

A beneficial consideration to this device is the fact that it will save time, and time is money. This means that less time is spent handling the pigs and identifying which ones are sick or of market-weight, which leads to more time the pigs are eating and more money gets put back into the pocket of the producer.

Environmental

One potential environmental consideration is the paint residue after it washes off the pig. Depending on the paint type and concentration, it could be harmful to the environment when it reaches a water source. However, the chosen brand, Sprayolo® livestock paint, contains three-quarters of water-based components and one-quarter of solvents. This suggests that it may have lower environmental impacts compared to paints with higher solvent content. Nonetheless, it is still important to consider factors such as proper application techniques, waste management, and disposal practices to minimize those risks associated with its use.

Another issue will be the waste when our device has reached its life span. Pipe material and electronics will need to be disposed of – or recycled – and other material waste from the fluid movement mechanism of a pump or air compressor.

Analysis of Alternatives

There were many aspects that were kept in mind when developing the solutions. With the determined criteria, major moving parts of the spray system were avoided. It was also imperative that the spray system will not scare the pigs in any aspect, which would hinder them from freely drinking. This leads to the conclusion of three potential solutions.

Design 1

The initial design solution involves a spray bar system enclosed within a PVC pipe. Its key feature is the retractable nozzles (refer to Figure 5), designed to retract into the PVC pipe to avoid direct exposure to power washing. However, drawbacks of this design are the requirement for a larger diameter PVC pipe to accommodate both the electronic triggering system and retractable nozzles and the added complexity of prompting the nozzles to retract when it needs to spray, which also adds the risk of retraction failure. Furthermore, this bar is strictly designed for a 4-stall system with set dimensions between each stall, so this design is not adaptable for pig barns with different stall configurations.

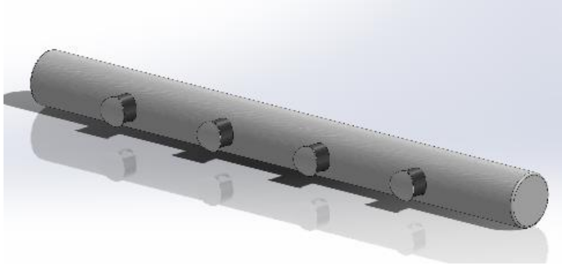


Figure 5. *Design 1 CAD Drawing*. Three-dimensional drawing of design solution 1 with retractable nozzles on a PVC pipe.

Design 2

The second design solution eliminates moving parts, favoring permanently mounted spray nozzles instead. This decision yields the benefit of a thinner PVC pipe and enhanced cost-effectiveness, as nozzles are not housed within the spray bar (see Figure 6). While maintaining the same rigid spray bar as design 1, this setup should ideally be easier to maintain. However, a potential issue with this design is the long-term impact of direct pressure washer cleaning on the nozzles. This can be addressed by utilizing higher-quality nozzles with integrated check valves, ensuring closure when the system is inactive and opening at specific pressure ratings during operation. Like the initial design, this solution is also limited to accommodating 4 stalls with set widths.

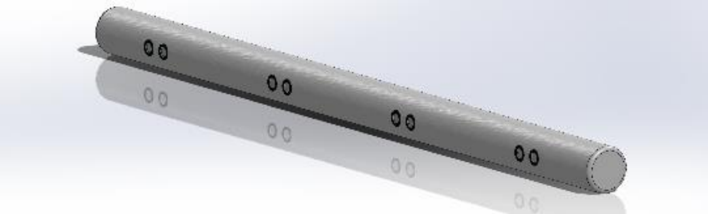


Figure 6. *Design 2 CAD Drawing.* Three-dimensional drawing of design solution 2 with permanent nozzles on the PVC pipe.

Design 3

The final design closely resembles design 2 but introduces the concept of individual spray modules (refer to Figure 7). This feature enables customization to align with the consumer's requirements based on the number of drinking stalls in their pens and the widths between them. Essentially, it offers increased versatility for securing in challenging environments. Furthermore, it would be mounted closer to the pigs and attached to adjustable tubing, allowing for accommodation for the ages of the pigs. However, a couple potential complications of this design are the complex tubing system for the paint and the risk of it being a safety hazard to the pigs due to the proximity of the nozzle. Additionally, there will be a higher initial cost to mount each module compared to a single complete spray bar. Nonetheless, the customization options inherent in this design ideally compensate for these drawbacks.

Figure 7. *Design 3 CAD Drawing.* Three-dimensional drawing of design option 3 with individual spray modules as opposed to a complete spray bar with nozzles for four stalls.

Constraint Analysis

Five primary constraints were chosen to determine if each design solution can achieve them. They are as follows:

1. The spray bar system cannot permanently obstruct Swine Monitoring Systems camera view.
2. The system must withstand the cleaning procedure.
3. The product cannot be a safety hazard to the pigs.
4. The cost of four spray-bar systems must not exceed $1,500.
5. The marking system must be able to accommodate the sizes of pigs between 8 and 30 weeks old.

All three design solutions would not permanently obstruct the Swine Monitoring camera view. However, the retractable nozzle design would be the most likely one to cause issues due to the larger housing pipe diameter and nozzles that temporarily protrude.

All three designs would withstand the cleaning procedure, but the designs with permanently exposed nozzles could see a higher rate of wear and tear due to constant exposure to pressurized water and cleaning solutions.

The two spray bar designs would not be a safety hazard to the pigs due to the position of the bars above the stalls and out of reach of the pigs. The individual module design could be at risk of being damaged by the pigs since it will be situated inside the stall and closer to them – potentially within reach of their snouts.

All three design solutions should stay within the $1,500 budget, especially since each design utilizes one electronic box that also holds two pumps for both spray colors. However, the individual module design could have higher production costs due to an increase in material used to position the nozzles and secure them separately.

The only design to feasibly accommodate each growth stage of the pigs is the individual module design. Since this solution would be mounted and attached to modifiable tubing within the stall that can be raised and lowered, the nozzles can also be adjusted to consistently spray similar regions, regardless of the pig's age. The other two spray bar designs would require extensive calculations to ensure the pigs would get sprayed when they are 8 and 30 weeks old with stationary nozzles. Furthermore, the nozzle characteristics and calculations for flow and orientation would alter since the paint would need to travel farther to reach the pig's back and be confined to a smaller wetted diameter once it reaches the pig.

Decision Matrix

Criteria Selection

All criteria were used to compare design solutions in decision matrices and help reach a final decision. They are as follows:

1. Mountable to a currently existing structure.
2. Add a visual dot to the neck or upper shoulders of swine.
3. Spray two different colors.
4. Paint lasts at least two days on the pig.
5. Paint should not contaminate any other surface than the pig.
6. Automated marking device should communicate with the Swine Monitoring System by sending information back when pigs are or are not sprayed.

Criteria Weighing

Below is Table 1, which was used to compare each criterion to one another using a pairwise strategy. Each criterion number corresponds to the list above. According to this approach, criteria 2 and 6 were deemed the most important (visible dot on neck or upper shoulders and communicating with both systems) and will take precedence over the other criteria when evaluating the design solutions.

Table 1. *Criteria Weight Comparisons*. Pairwise comparison table was utilized to weigh each criterion.

	Mountability	Visual Dot	2 Colors	Paint Durability	Contamination	Communication	Score
Mountability		0	0	1	0	0	1
Visual Dot	1		1	1	1	0	4
2 Colors	1	0		1	1	0	3
Paint Durability	0	0	0		0	0	0
Contamination	1	0	0	1		0	2
Communication	1	1	1	1	1		5

Below (Tables 2 – 7) are the pairwise comparisons of the design solutions to each criterion. The combined scores are utilized in the final decision matrix as multipliers, aligning with the total design scores. In the blue boxes, a '1' signifies that the row solution is more significant than the column solution, while '0' indicates the column solution is prioritized over the row solution. Zero scores indicate that meeting the given criterion will pose greater difficulty compared to the other solutions.

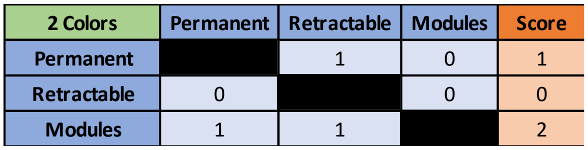
Table 2. *Criterion 1 Versus Designs.* Pairwise comparison of each design solution to the ability for it to be mounted to a current structure.

Mountability	Permanent	Retractable	Modules	Score
Permanent		1	0	1
Retractable	0		0	0
Modules	1	1		2

Table 3. *Criterion 2 Versus Designs.* Pairwise comparison of each design solution to adding a visual dot to the upper shoulders or neck.

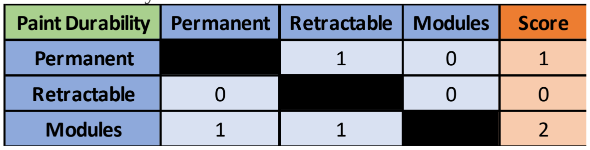
Visual Dot	Permanent	Retractable	Modules	Score
Permanent		1	0	1
Retractable	0		0	0
Modules	1	1		2

Table 4. *Criterion 3 Versus Designs.* Pairwise comparison of each design solution to the ability of the system to spray two colors.



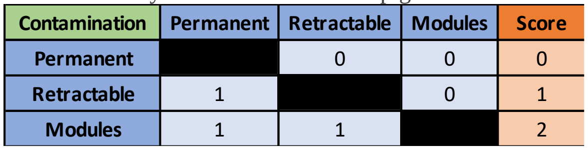
2 Colors	Permanent	Retractable	Modules	Score
Permanent		1	0	1
Retractable	0		0	0
Modules	1	1		2

Table 5. *Criterion 4 Versus Designs.* Pairwise comparison of each design solution to the ability of the paint to stay on for at least two days.



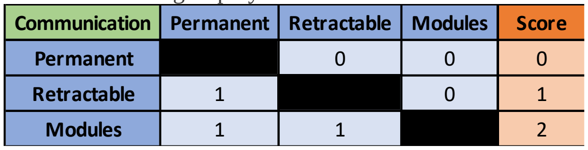
Paint Durability	Permanent	Retractable	Modules	Score
Permanent		1	0	1
Retractable	0		0	0
Modules	1	1		2

Table 6. *Criterion 5 Versus Designs.* Pairwise comparison of each design solution to the ability of the paint to not contaminate any other surface than the pig.



Contamination	Permanent	Retractable	Modules	Score
Permanent		0	0	0
Retractable	1		0	1
Modules	1	1		2

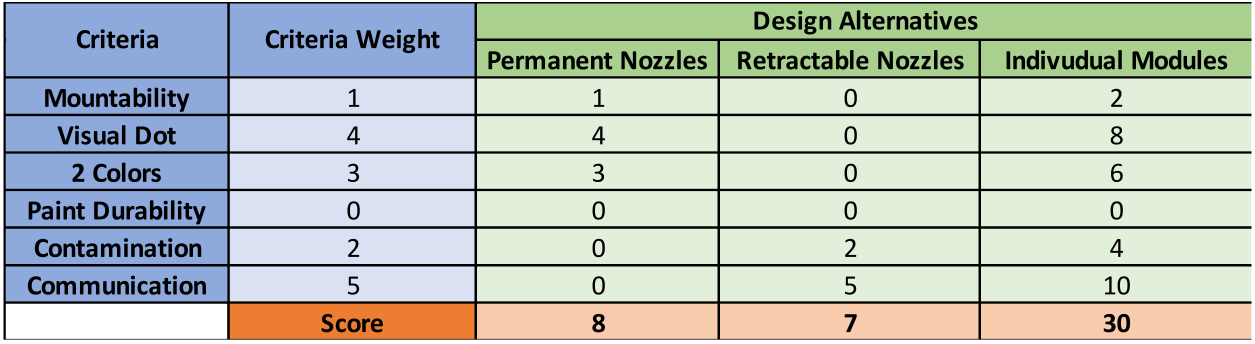
Table 7. *Criterion 6 Versus Designs.* Pairwise comparison of each design solution to the communication between the marking device and the monitoring system through sending information back and forth when a pig is in a stall and if it does or does not get sprayed.



Communication	Permanent	Retractable	Modules	Score
Permanent		0	0	0
Retractable	1		0	1
Modules	1	1		2

The Pugh decision matrix below (Table 8) organizes the scores to help us reach a final design decision. The criteria weight column's numbers (in blue) come from the score on the first criteria analysis table (Table 1) when the criteria are compared to each other. The design alternative values are found from the scores of the design solution pair-wise comparisons (Tables 2 – 7) for each criterion, then multiplied by the criteria weight value in the blue column. The final score is reached by adding up each column for each design solution.

Table 8. Final Design Decision Matrix. Pugh decision matrix to help reach a final design solution.



Criteria	Criteria Weight	Design Alternatives		
		Permanent Nozzles	Retractable Nozzles	Indivudual Modules
Mountability	1	1	0	2
Visual Dot	4	4	0	8
2 Colors	3	3	0	6
Paint Durability	0	0	0	0
Contamination	2	0	2	4
Communication	5	0	5	10
	Score	**8**	**7**	**30**

Based on these scores, the individual module design emerges as the preferred solution, given its higher score. Criteria 2 and 5 held the highest importance for this design. Notably, individual modules are most effective in meeting the visual spray dot criteria due to their attachment location on the adjustable drinker, and its ability to effectively communicate between the automated marking device and the Swine Monitoring System. The absence of a score for criterion 4, regarding the durability of the paint, is due to the weight analysis, but does not necessarily impact the module design. However, the low score on criterion 1, which is its ability to mount to existing structures, raises concerns since it relies on attachment to adjustable drinker tubing, which may not be present in every pig barn. Nevertheless, the individual module design remains the favored solution for fulfilling the project's objectives, encompassing all criteria and more.

Description of Final Design

Nozzle Components

The individual module design consists of dual nozzles reaching into the stalls and attaching to adjustable square tubing, which hold the drinker nipples. The nozzles will be housed in a 3D printed structure that will hold the nozzles at the correct spray angle to consistently mark the pigs on their upper back and shoulder region. This housing structure will be attached at the bottom of protective tubing and will hold the fluid lines for both colors of paint – green and pink. The fluid lines will run all the way up into the pump and electronic box, which receive its paint supply from attached reservoirs (see Figure 8).

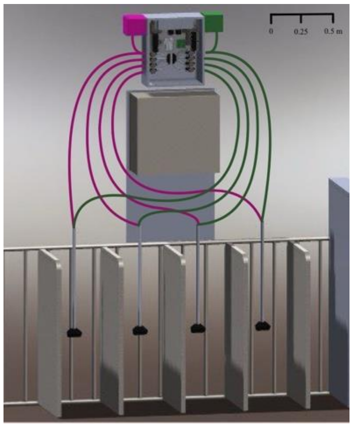


Figure 8. *Complete CAD Drawing of Final Design.* Nozzle and fluid line configuration within the pen and each stall. Each nozzle compartment will be attached 9 inches above the drinker nipple and fluid lines will run into the pump box, which receive its supply from the reservoirs attached at the top of the box.

Fluid Flow Components

Basic fluid pumps were utilized to deliver fluid to the nozzles (see Figure 9). These pumps boast a maximum flow rate of 1 gallon per minute. However, to achieve the desired output pressure of 40 psi necessary to supply the nozzles, the flow rate is adjusted to approximately 0.6 to 0.7 gallons per minute. The inlet line is connected to the paint reservoir outside the box, while the outlet line is linked to a check valve, which prevents backflow and maintains a constant pressure through the paint tube. From there, a manifold directs fluid to the four solenoids used to control the dispensing of paint to the nozzles in each stall. These solenoids are triggered with relay switches and power boards on the instrumentation panel, detailed below. Subsequently, the fluid lines are routed from the solenoids to the stalls. This configuration remains consistent for both paint colors and is symmetrically positioned on the board. All these components are housed within a polycarbonate box and affixed to a steel plate located at the box's bottom. To ensure watertight seals at all inputs and outputs, the fluid line openings cut through the box are sealed using ICOTEK® cable grommets. Figure 10 illustrates the fluid component configuration on the steel plate.

Figure 9. *Selected Fluid Pump.* Chosen fluid pump for the final design. Commonly used in small agricultural spray applications requiring low flow rates. The maximum flow rate is 1 gallon per minute, maximum output pressure is 40 psi, and power needed is 12 V. It also features self-priming and a 3/8” hose outlet barb.

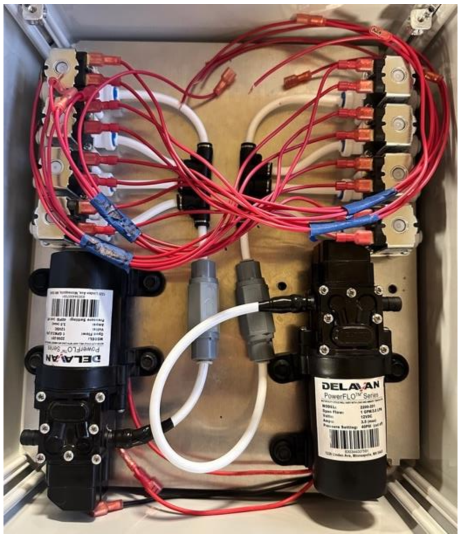


Figure 10. *Fluid Panel Layout.* Pump and fluid component layout within the polycarbonate box. Each side represents one paint color and are symmetrical to each other. The grey pieces connected at the pump outlets are the check valves, which connect to the manifolds that direct flow into solenoids. The red wires attached to the solenoids will be connected to the relay switches on the instrumentation board.

Instrumentation Components

The instrumentation board resides above the fluid plate within the same polycarbonate box, occupying only half of the available space, as depicted in Figure 11. This design ensures that in the event of any leaks from the pump system, no electronics would be at risk of damage. The primary requirement was a power source, necessitating 12 volts to activate the pumps. However, as an ARDUINO board cannot safely handle 12 volts, a voltage regulator was incorporated to reduce it to 5 volts. Wiring extended from the ARDUINO board's digital pins to relay switches, facilitating automated control over which solenoids are opened. Additionally, the ARDUINO board interfaces with the current Swine Monitoring System and oversees both paint pumps, a process elaborated in the *Programming Code* section detailed in the Appendix, but below in Figure 13 is a simple block diagram of the code logic. Ground and power terminal bus bars were employed to streamline component organization and served as the primary connection point between all elements, as shown in the wiring diagram in Figure 12 complete with all wiring connections.

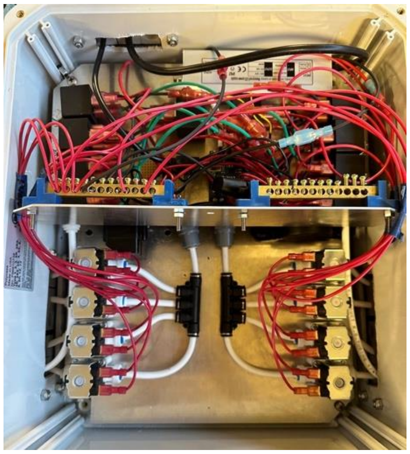


Figure 11. *Polycarbonate Box Components.* The top panel, located above the fluid assembly, plays a vital protective role, particularly when upright, guarding against potential leaks. The white rectangle represents the power source, supplying energy to the ARDUINO, relay switches, and solenoids via the terminal bars at the base of the electronic panel. Relay switches, depicted as small black boxes at the far ends of the panel, oversee critical functions. Situated centrally beneath the wires, the ARDUINO and voltage regulator circuit board optimize operational efficiency.

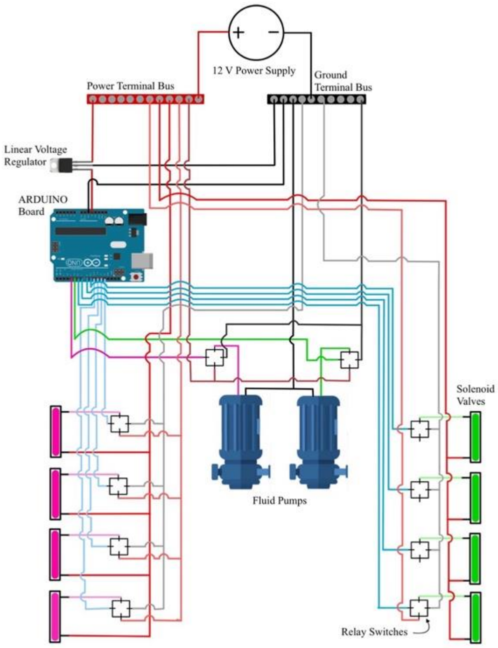


Figure 12. *Wiring Diagram.* Wiring diagram of electronic components and their connections.

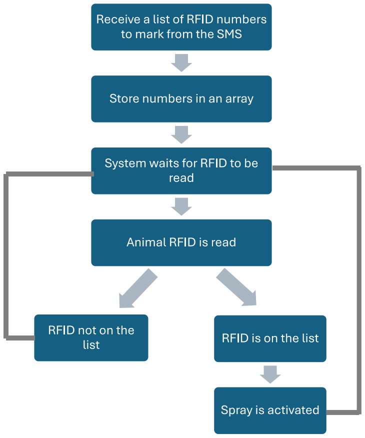


Figure 13. *Basic Coding Process.* Block diagram of coding and communication process between the Swine Monitoring System and the Automated Marking Device.

Alternatives and Suggestions to Final Design

If budget constraints were not a concern in the design process, several enhancements could be made. Pressure and flow meters would be strategically placed at various pump outlet locations to form a comprehensive monitoring system. This setup would facilitate the identification of fluid flow issues in case of system malfunctions. Instead of installing check valves immediately after the pump, they would be integrated into the nozzles or positioned just before them. Ideally, the nozzles themselves would incorporate check valves. Additionally, pump connection adapters would be employed for both inlet and outlet connections. Currently, the pump lines are secured with fluid tape to prevent leaks, but either gluing the lines or sourcing appropriate adapters would ensure robust connections.

Budget

The objective was to limit the cost of four systems, each equipped with four stalls, to under $1,500. The creation of a single system with four stalls was successfully executed at a cost of $340.01, totaling $1,360.04 for four systems. This target was met with the final design, offering flexibility for further refinement if needed. Below is a breakdown of component expenses (see Table 9) along with the hourly cost encompassing research, design, testing, and meeting hours, billed at $50 per hour for project-related tasks.

Table 9. *Full Budget List.* All items bought and utilized for the final design product. Labor was calculated at $50/hour per class requirement.

Item	Amount	Total Cost
Fluid Pump	2	$59.98
Nozzle	8	$24.32
Manifold	2	$13.99
Solenoid Valve	8	$15.00
Check Valve	2	$11.93
Paint Tubing	50 ft	$10.00
Electrical Spade Connectors	60	$10.00
Power Supply	1	$20.00
Relay Switch	10	$15.00
Electrical Ground Bar	2	$5.00
Electrical Wire	10 ft	$1.30
Hardware	50	$30.00
IcoTek	3	$55.50
Polycarbonate Box	1	$50.00
Paint Gallon	2	$71.90
Research Hours	78	$3,900
Design and Testing Hours	107	$5,350
Meeting Hours	96	$4,800
Total for Single Spay System with Hours		**$14,390.01**
Total for Single Spray System without Hours		**$340.01**
Total for 4 Spray Systems without Hours		**$1,360.04**

References

Brown-Brandl, T. M., Adrion, F., Gallmann, E., & Eigenberg, R. (2018). Development and validation of a low-frequency RFID system for monitoring grow-finish pig feeding and drinking behavior. *10th International Livestock Environment Symposium (ILES X)*. https://doi.org/10.13031/iles.18-041

Condotta, I. C. F. S., Brown–Brandl, T. M., Da Silva Miranda, K. O., & Stinn, J. P. (2018a). Evaluation of a depth sensor for mass estimation of growing and finishing pigs. *Biosystems Engineering*, *173*, 11–18. https://doi.org/10.1016/j.biosystemseng.2018.03.002

Condotta, I. C. F. S., Brown–Brandl, T. M., Stinn, J. P., Rohrer, G. A., Davis, J. D., & Da Silva Miranda, K. O. (2018b). Dimensions of the modern pig. Transactions of the ASABE, 61(5), 1729–1739. https://doi.org/10.13031/trans.12826

Dailiana, H. (2008, March 1). *Injection injuries: seemingly minor injuries with major consequences*. PubMed Central (PMC). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2532970/

The National Institute for Occupational Safety and Health (NIOSH) (2023, January 25). NIOSH sound level meter app. https://www.cdc.gov/niosh/topics/noise/app.html

NSF International. (2019, February 8). NSF global animal wellness standard (pig production). *NSF International*.https://d2evkimvhatqav.cloudfront.net/documents/nsf_animal_wellness_program_standard_pig_production.pdf?v=1594929782

Talling, J., Waran, N., Wathes, C. M., & Lines, J. (1996). Behavioural and physiological responses of pigs to sound. *Applied Animal Behaviour Science*, *48*(3–4), 187–201. https://doi.org/10.1016/0168-1591(96)01029-5

Uhm, C., Jeong, H., Lee, S. H., Hwang, J. S., Lim, K. M., & Nam, K. T. (2023). Comparison of structural characteristics and molecular markers of rabbit skin, pig skin, and reconstructed human epidermis for an ex vivo human skin model. *Toxicological Research*, *39*(3), 477–484. https://doi.org/10.1007/s43188-023-00185-1

Appendix

Engineering Assessments

- 3D model of the system.
- Pressure and flow characteristic calculations.
- Nozzle wetted diameter calculations.
- Spray angle calculations to accommodate pig growth.
- Selection of the correct nozzle based on calculations and testing procedures.
- Noise testing procedure.
- Programming the system to trigger the correct nozzle at the correct time.
- Construction of a functional spray bar.

3D Model

Utilizing computer-aided design software, a three-dimensional model was generated of the system and its components. This enabled us to accurately depict the location and orientation of the automated marking device and its integration with the current Swine Monitoring System, as shown in Figure 14 below.

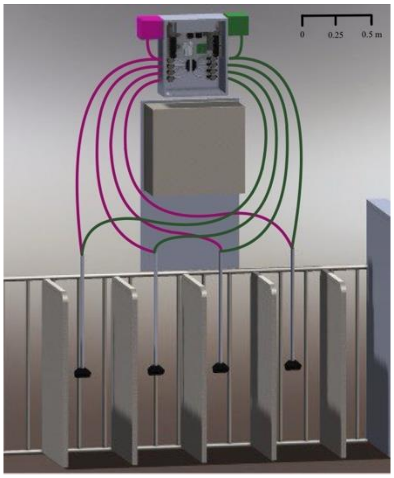


Figure 14. *CAD Model of Automated Marking Device.* CAD model of the automated marking device integrated into the stalls and in collaboration with the Swine Monitoring System.

Pressure and Flow Calculations

The system's essential components encompass pressure and flow characteristics. To facilitate the calculation process, several valid assumptions were made: steady-state and constant flow, negligible pressure drop due to elevation, and equal densities of water and paint due to paint properties. The given and known information includes an inlet flow rate of 0.65 gallon per minute at 40 pounds per square inch of inlet pressure provided by the pump, an inner tube diameter of 0.162 inches, water density of 62.4 pounds per cubic foot, and inner nozzle diameters of 0.057 inches, 0.079 inches, and 0.110 inches. Initially, the velocity at the inlet is calculated using the equation below.

$$V_{in}\left[\frac{ft}{s}\right] = \frac{4Q_{in}\left[\frac{gal}{min}\right]}{\pi d_{tube}^2[in]} * \left[\frac{231\ gal}{in^3}\right] * \left[\frac{1\ min}{60s}\right] * \left[\frac{1\ ft}{12\ in}\right]$$

The calculated inlet velocity was 10.1 ft/s. Then using that value, outlet velocity for each nozzle size is calculated with equation aside using the assumption that inlet flow rate is equal to the outlet flow rate, which correlates to the following equation.

$$V_{out}\left[\frac{ft}{s}\right] = \frac{d_{tube}^2[in]V_{in}\left[\frac{ft}{s}\right]}{d_{nozzle}^2[in]}$$

The outlet velocities for each nozzle were found to be 81.7 ft/s, 42.6 ft/s, and 21.9 ft/s. To finally determine the outlet pressure at each nozzle size, Bernoulli's equation was used and is formatted below.

$$P_{out}\left[\frac{lb}{ft * s^2}\right] = P_{in}\left[\frac{lb}{ft * s^2}\right] + \frac{1}{2}\rho\left[\frac{lb}{ft^3}\right]\left(V_{in}^2\left[\frac{ft}{s}\right] - V_{out}^2\left[\frac{ft}{s}\right]\right)$$

The outlet pressures were calculated as -4.29 psi, 28.5 psi, and 37.4 psi. Since the smallest nozzle size's output pressure is negative, the flow rate or inlet pressure may be adjusted during testing to function. Furthermore, all these calculated pressures are below the 100-psi threshold, so all are safe to use.

Nozzle Wetted Diameter Calculations

To determine the wetted diameter of the sprayed paint, data from *Dimensions of the Modern Pig* (Condotta et al.,b) was utilized. The below equation with input values for certain pig dimensions from the article was the primary source for the wetted diameter calculations. Di is the desired dimension in centimeters, a and b are constants given based on the calculated dimension, and M is the body mass in kilograms of the pig at different ages. Figure 15 shows each dimension that can be determined with this equation.

$$Di\ [cm] = aM[kg]^b$$

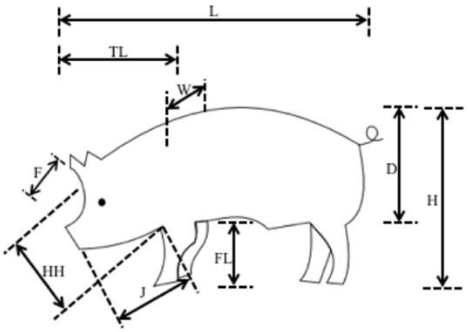
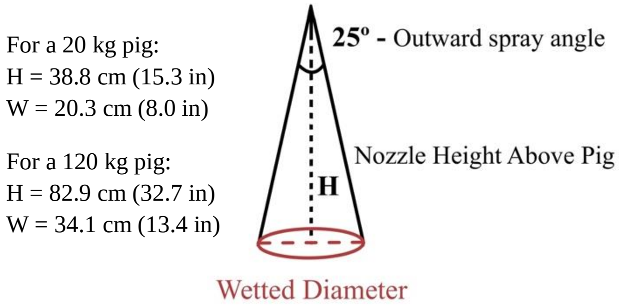


Figure 3. Important dimensions of a pig (L = total length, TL = taper length (from shoulders to snout), W = width of body at shoulders, F = face length (from nose to base of ears), HH = head height (from base of jowl to top of head between ears), J = jowl length (from nose to front legs), FL = length of front legs, D = depth (from lowest point on belly to top of back), and H = height.

Figure 15. *Pig Dimensions.* Figure taken from Dimensions of the Modern Pig (Condotta et al., 2018b). These dimensions can be calculated using the above equation with given a, b, and M values, depending on the desired dimension.

The following diagram (Figure 16) represents the process used to determine both the nozzle height above the drinker nipple and the corresponding wetted diameter. An assumption that the pig's shoulders will be in line with the drinker nipple is utilized to simplify calculations. The 25º outward spray angle is from the selected nozzle characteristics.


For a 20 kg pig:
H = 38.8 cm (15.3 in)
W = 20.3 cm (8.0 in)

For a 120 kg pig:
H = 82.9 cm (32.7 in)
W = 34.1 cm (13.4 in)

Figure 16. *Wetted Diameter Diagram.* Front view of the nozzle with the desired variables and calculated values for both extreme weights.

The maximum wetted diameter was calculated first, which is the maximum width across the pigs' back to accommodate it at both its youngest and oldest ages. The Height dimensions were first calculated using the above equation at 20 kg and 120 kg body masses, which represent the smallest and largest weights of pigs in the facility. That yielded heights of 38.8 cm and 82.9 cm. Using the same equation and body masses but with Width parameters, the calculated width dimensions were 20.3 cm and 34.1 cm, respectively. Converting into English units, the maximum wetted diameter range needed to be within 7.98 and 13.4 inches wide. Using trigonometric rules, the nozzle height range was calculated to be within 18.0 and 30.3 inches at the respective wetted diameter range.

However, a nozzle height of 18 to 30 inches may not be achievable with the stall layout due to the orientation of the cameras for the Swine Monitoring System. Furthermore, a wetted diameter that covers the entire width of the pig is unnecessary. If the wetted diameters are cut in half to be between 4 and 7 inches, the nozzles would be at 9 or 16 inches above the drinker nipple, which is achievable with the current stall layout.

The final wetted diameter was decided to be 4 inches, so the nozzle will be situated 9 inches above the drinker nipple. This height is deemed adequate to avoid pig interference and the wetted diameter is more than large enough to be seen by a handler from 50 or more feet away. If concerns arise about pigs reaching the nozzle, the wetted diameter can be made larger, which increases the height of the nozzle above the pig. However, the calculated diameter may differ from the actual diameter achieved when the nozzle is operating, so adjustments can be made when the system is installed in the pig barn to accommodate larger or smaller diameters or higher or lower nozzle heights.

Spray Angle Calculations

To accommodate the pig's size as they grow older, the nozzle will need to spray outward at an angle to consistently mark their shoulders or upper back. The below diagram (Figure 17) shows the orientation and the process used to calculate the spray angle.

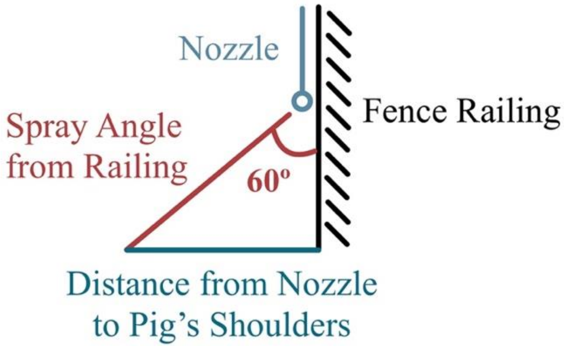


Figure 17. *Spray Angle Diagram.* Diagram of the calculation process to determine the spray angle from the railing and the distance from the nozzle to the pig's shoulders.

Using the same equation from *Dimensions of the Modern Pig* (2018b), the Taper Length dimension was calculated at 20- and 120-kilogram body masses. Since the desired solution design will be attached to the adjustable drinker nipples, the assumption that the nozzle will spray in the same general region of the pig's back can be made. The taper length range was calculated to be 28.6 and 40.5 centimeters at the smallest and largest weights, respectively. To prevent the risk of spraying too close to the head, the larger taper length measurement is utilized to determine the distance from the nozzle to the pig's shoulders, which is 16 inches. Using trigonometry, the spray angle is calculated to be 60º from the vertical position. To make sure 16 inches wasn't too far to spray when the pig is young, the Total Length dimension was calculated and determined to be over 10 inches longer than the nozzle distance, which ensures that the nozzle will not spray over the pig when it weighs 20 kilograms.

Nozzle Selection

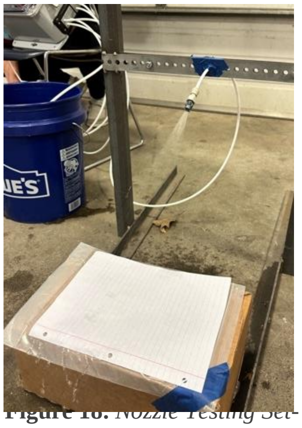


Figure 18. *Nozzle Testing Set-Up.* The spray pad (paper) is 16 horizontal inches and 9 vertical inches from the nozzle while the nozzle is held at a 60º angle. The pump is running water through the system outputting to the three nozzles, each tested separately with the same configuration.

Using the pressure and flow calculation process, the smallest nozzle size had a negative output pressure, which suggests parameters would need to be adjusted to produce a positive pressure. Furthermore, all calculated pressures were below the 100 pounds-force per square inch constraint, so those three sizes were chosen to undergo testing with our pump configuration.

Three nozzle sizes were tested with three main variables to compare – spray angle, wetted diameter, and flow appearance. Each nozzle was attached to the hose at 9 inches above the floor and the hose was held at about a 60º angle from the vertical position to reach a spray distance of about 16 inches. To measure the wetted diameters, paper was placed at 16 horizontal inches from the nozzle and at 9 inches vertically (refer to Figure 18). As the water sprayed the paper, the wetted diameter was measured and compared to calculated diameters, as shown in Figure 19. All nozzles appeared to fan out at about 25º degrees, the manufacturer's specified spray angle, as they hit the paper. However, all measured diameters were wider than the desired and calculated diameter based on the nozzle placements, almost double for every test (see Table 10).

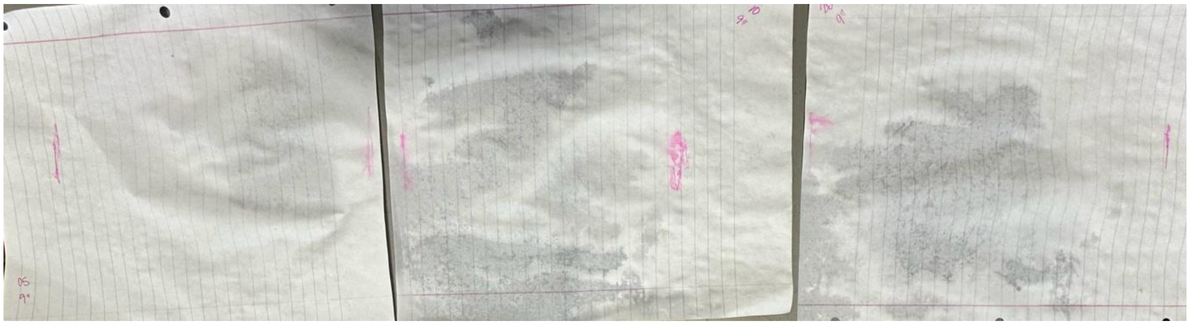


Figure 19. *Wetted Diameter Measurements.* The three tested nozzles' – 05, 10, and 20 – measured wetted diameters in order. The pink lines on either side of the water marks represent the edges of the diameters. By observation, size 10 had the smallest diameter in comparison to 05 and 20.

Table 10. *Nozzle Testing.* Documented measurements and notes from the nozzle testing.

Nozzle Size (ID in inches)	Nozzle Size	Input Pump Pressure (psi)	Height of Nozzle	Measured Output Spray Diameter (in)	Calculated Output Spray Diameter (in)	Comments about Droplet Size/Spray
0.057	5	40	9	8.5	4	Finest droplet size
0.079	10	40	9	7	4	Medium droplet size
0.11	20	40	9	8.5	4	Seemed to spray more aggressively compared to other nozzles

As depicted in the above table and figure, the smallest measured wetted diameter was 7 inches from nozzle size 10. From these tests and considerations, we concluded that that nozzle will be the one implemented into the final design (see Figure 20). However, to achieve a smaller wetted diameter, one of two things need to occur. Either the nozzles need to be situated closer to the pig, such as in Figure 21 where the nozzle is 6 inches above the tape measure and reaching a reasonable diameter of 2-3 inches, or the pressure to the nozzles needs to be lowered. The latter is much more realistic and would be done by implementing a pressure regulator on the pump system and adding to the code to adjust the pressures. It would not be recommended to situate the nozzles only 6 inches above the drinker nipples because the pigs could easily reach and destroy them.

Figure 20. *Selected Nozzle.* Nozzle size 10 selected for the final design. It features a 25º horizontal spray angle and a maximum operating pressure of 40 psi.

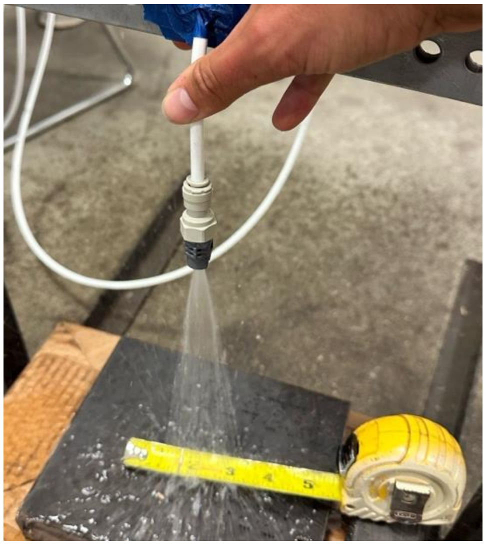


Figure 21. *Wetted Diameter Reduction.* Snapshot of the smaller wetted diameter being achieved with a reduced height between the nozzle and the tape measure. The water is hitting between about 1 and 3.5 inches.

Noise Testing

To ensure the operational pump system remained within the acceptable noise level of 80 dB, a noise assessment was carried out. Utilizing the NIOSH Sound Level Meter app, endorsed by the Centers for Disease Control and Prevention, noise levels were measured at the site of the operation. This application boasts an accuracy of within 2 dB of the detected value (NIOSH, 2023). While the system was in operation, the app continuously monitored the decibel levels at or slightly below the operational nozzle (see Figure 22). The average noise level recorded was just under 70 dB, with a peak of 74 dB, both well below the established threshold. These findings affirm that the pump system operates within the permissible noise limit of 80 dB.

Figure 22. *Noise Testing.* Snapshot of sound assessment using the NIOSH app.

System Programming

The ARDUINO platform was employed to manage the spraying system. Its primary functions include receiving a list of RFID numbers requiring marking with specific colors, monitoring the Swine Monitoring System for RFID number readings from the drinking stalls, identifying RFID numbers on the to-spray list, marking them accordingly while still in the stall, adding these numbers to an acknowledgment list, and compiling a final acknowledgment list of RFID numbers that were or were not sprayed to transmit back to the Swine Monitoring System at day's end. Additional functionalities encompass a priming period to initialize pumps before the workday begins, preventing the repeated spraying of pigs already on the acknowledgment list each time they enter the stall, and resetting both the to-spray and acknowledgment lists once the latter is sent to the Swine Monitoring System at the close of the workday (refer to *Programming Code* below for detailed code documentation).

Device Construction

Each component of the Automated Marking Device was constructed individually, awaiting connection until it can be seamlessly integrated into the operational pig barn. This integration is necessary to accommodate the pen and drinking stall's size and space constraints. While the fluid and electronic box have been configured, paint hoses must be sized according to the paint reservoir's location and the distances to each stall. A nozzle housing structure has been designed, pending potential alterations depending on attachment components, before proceeding to 3D printing (refer to Figure 23). However, for testing purposes, makeshift "stalls" were configured to replicate the widths between stalls for each nozzle pair. Figure 24 illustrates a preliminary setup of the system within the barn, with the electronic box positioned above the stalls, and the nozzles reaching down into them, held at approximately 9 inches above the pig.

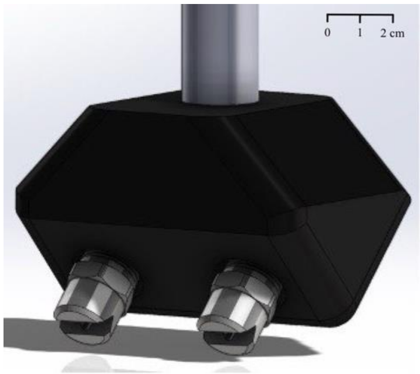


Figure 23. *Nozzle Housing CAD Drawing.* CAD drawing of designed nozzle housing structure that attaches to a protective hose that runs the paint lines through to the polycarbonate box and reservoir.

Figure 24. *Automated Marking Device Test Configuration.* Testing set-up representing drinking stall widths and positioning of components.

Programming Code

Below is the complete documented ARDUINO code for all mechanisms described under *System Programming* of the Engineering Assessment section.

```
#include <SoftwareSerial.h>
#include <Arduino.h>
// Define stall numbers
#define STALL_1 1
#define STALL_2 2
#define STALL_3 3
#define STALL_4 4

// Define pump pins
const int pumpPinPink = 4; // Digital pin for pink paint pump
const int pumpPinGreen = 5; // PWM pin for green paint pump

// Define "to-spray" list
String LIST_MASTER[10][2]; // Assuming a maximum of 10 RFID numbers in the list
  // LIST_MASTER can hold up to 10 rows and 2 columns of data

// Define ACK_LIST to store RFID numbers sprayed and their status (sprayed or not sprayed)
String ACK_LIST[10][2]; //Two-dimensional array to hold up to 10 RFID numbers and their status

// Define serial communication
SoftwareSerial serialPort(2, 3); // RX, TX

// Function prototypes
```

```
String checkToSprayList(String rfidNumber);
void sprayPaint(int pumpPin);
void sendAckList();
void resetLists();

//Timer variables
unsigned long previousAckTime = 0;
unsigned long previousResetTime = 0;
const unsigned long interval = 14UL * 3600UL * 1000UL;
  // 14 hours in milliseconds
  // Assuming 14 hour workdays
const unsigned long primingPeriod = 6 * 1000;
                // Priming period to run the pump for 6 seconds at the start of the work day

void setup() {
  Serial.begin(9600);
  serialPort.begin(9600);
  pinMode(pumpPinPink, OUTPUT); // Initialize pink paint pump pin as output
  pinMode(pumpPinGreen, OUTPUT); // Initialize green paint pump pin as output

  // Priming period: Activate pumps for priming
  digitalWrite(pumpPinPink, HIGH);
  digitalWrite(pumpPinGreen, HIGH);
  delay(primingPeriod); // Priming period delay
  digitalWrite(pumpPinPink, LOW);
  digitalWrite(pumpPinGreen, LOW);
}
void loop() {
  // Listen for RFID number and stall number from each stall
  if (serialPort.available() > 0) {
    String data = serialPort.readStringUntil('\n');
    int stallNumber = data.charAt(0) - '0';
    String rfidNumber = data.substring(2);

    // Check if RFID number is on "to-spray" list
    String colorNeeded = checkToSprayList(rfidNumber);

    // If RFID number is on the list, spray the correct color
    if (colorNeeded != "") {
      if (colorNeeded == "Pink") {
        sprayPaint(pumpPinPink);
      } else if (colorNeeded == "Green") {
        sprayPaint(pumpPinGreen);
      }

      // Add RFID number to ACK_LIST
      ACK_LIST[stallNumber - 1][0] = rfidNumber; //Store RFID number
      ACK_LIST[stallNumber - 1][1] = "Sprayed"; //Update status to sprayed

      // Delay for 3 seconds
      delay(3000);

      // Turn off both pumps
```

```
      digitalWrite(pumpPinPink, LOW);
      digitalWrite(pumpPinGreen, LOW);
    }
  }

  // Check if it is time to send ACK_LIST
  unsigned long currentTime = millis();
  if (currentTime - previousAckTime >= interval) {
    // Add unsprayed RFID numbers from LIST_MASTER to ACK_LIST
    for (int i = 0; i < 10; i++) {
      if (LIST_MASTER[i][0] != "") {
        bool sprayed = false;
        for (int j = 0; j < 10; j++) {
          if (LIST_MASTER[i][0] == ACK_LIST[j][0]) {
            sprayed = true;
            break;
          }
        }
        if (!sprayed) {
          for (int j = 0; j < 10; j++) {
            if (ACK_LIST[j][0] == "") {
              ACK_LIST[j][0] = LIST_MASTER[i][0];
              ACK_LIST[j][1] = "Not Sprayed";
              break;
            }
          }
        }
      }
    }
   sendAckList(); // Send ACK_LIST to software serial
   previousAckTime = currentTime; // Reset the timer
  }

  // Check if it is time to reset LIST_MASTER
  if (currentTime - previousResetTime >= interval) {
    resetLists(); //reset LIST_MASTER and ACK_LIST
    previousResetTime = currentTime; //Reset the timer
  }
}

String checkToSprayList(String rfidNumber) {
  // Search for RFID number in LIST_MASTER
  for (int i = 0; i < 10; i++) { // Assuming a maximum of 10 RFID numbers in the list
    if (LIST_MASTER[i][0] == rfidNumber) {
      // If RFID number found, return color needed
      // LIST_MASTER[i][0] represents the RFID number stored in the first column of the ith row
      return LIST_MASTER[i][1];
      // represents the corresponding color needed stored in the second column
    }
  }
  // If RFID number not found, return empty string
  return "";
}
```